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Relation between thermal and electrical conductivities in the ionosphere

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Abstract : Considering the ions and electrons in the ionosphere to be moving to some extent freely, the relation between thermal (K) and electrical ( ) conductivities has been studied. Data from PRL (at 11.00 A.M. on March, 1987) have been used in computing these conductivities at different altitudes. It is seen that K and σ are not linearly related. Attempt has been made to explain this fact in this work.

Keywords : Ionosphere, thermal and electrical conductivity, viscous dissipation, random encounters, quasi-neutrality.

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1. Introduction

The ionosphere may be considered as ionized (fully or partially) medium having free ions and electrons at random motion. Such movements may be controlled by applied or induced electric or magnetic fields and winds etc. Due to the motion of the ionized particles, electric currents may flow in certain restricted directions, the magnitude of which will depend upon the properties of the region under consideration.

Again, the ionospheric regions become heated by absorbing the EUV from sun and other stellar bodies ; infrared emissions ; viscous dissipation and the effects associated with geo-magnetic activities. Amongst these the EUV is the main contributor as pointed out by Straus *et al* (1975). Both the electric and heat flux depend on the rate of diffusion of the ions and electrons. But the later, as a result of their smaller mass, will have greater velocity contributing mainly to the flow of flux in both cases. Thus, the conductivities of a region may be attributed mainly to the motion of electrons.

In the present work, the relationship between thermal and electrical conductivities has been studied for different regions of the ionosphere. It has been assumed that the properties of a region remain constant over small horizontal slabs. The effects of ionic motion have been neglected for the present. Considerations have been made about the electrical and thermal conductivities with some restrictive assumptions as follows :

(i) The loss of energy due to the above process is less than that due to random encounters as mentioned by Pines and Bohm (1952),

(ii) The electric field and temperature gradients are weak as in Spitzer and Harm (1953),

(iii) For quasi-neutrality and constant pressure, the diffusion velocities are negligibly small as in Meador and Staton (1965),

(iv) Temperature gradient exists in vertical direction along which the conductivities may be considered.

The dip-equatorial regions upto an altitude of 200 kms have been considered since the data in this region is available. These regions may be assumed to be partially ionized and both the ions and electrons take part in electrical flux flow while the neutrals, ions and electrons all are having considerable roles in transferring heat flux. In the present work, only the transport due to the electrons has been considered for simplicity. It may be mentioned that the effects of all other particles will be considered in details in later works.

The importance of this work is as follows : This study will give us an idea about the rate of diffusion of ions (electrons in this case) in an ionospheric region. Also, the flow of flux could be estimated from such study. From the relation between K and σ_p an idea about the thermal and electrical behaviour of the medium could be made. This will lead to a knowledge about the nature of the medium (ionospheric regions). The estimation of thermal conductivity (K) may give an idea about the heat conduction through the region concerned and the ionospheric heating by the transmission of UV, X-rays etc. coming from sun and other sources.

2. Thermal and electrical conductivities

Transport effects due to electrons are important in the mentioned regions. Since these are partially ionized, the interaction of electrons, ions and neutrals have to be considered for greater accuracy. For simplicity, only the ions and neutrals have been assumed to possess Maxwellian velocity distribution as in Shunk (1975) and m_e/m_i, m_e/m_n (m_e=mass of electrons, m_i=mass of ions, m_n=mass of neutrals) may be neglected compared to unity. Although the ionosphere is a weakly ionized plasma, yet the main contributor to heat transport may be assumed to be the electrons which is same as in fully ionized plasma.

Under the above assumptions and neglecting the effect of electron-neutral interactions in a fully ionized plasma composed of electrons and one singly ionized species, Shunk (1975) has given the following expression for coefficient of thermal conductivity (K) by eliminating the Coulomb collision frequencies,

$$K = \frac{75}{4\sqrt{\pi}(8+13\sqrt{2})} \frac{k(kT_e)^{5/2}}{m_e^{1/2} e^4 \log \Lambda} \tag{1}$$

where k = Boltzmann constant, T_e = electron temperature at the altitude of the region concerned, e = cherge and m_e = mass of the electron, $\Lambda = \frac{3(kT_e)^{3/2}}{2e^3 (N\pi)^{1/2}}$, N = electron density of the region. Since electron is taken to be the main heat carrier and the effects of others are neglected both for weakly and fully ionized plasma, hence eq. (1) may be used for the regions considered here.

In absence of wave propagation and external electric and magnetic fields, the conductivity of a region depends mainly on interaction of electrons with other particles and on the properties of the medium. Under these circumstances, the effective conductivity is Pedersen conductivity as mentioned by Barker and Martin (1953). Again, conductivity depends on the ratio of gyro-frequency (ω_i) to collision frequency (ν) for both ions and electrons. Due to the difference in masses, the ions and electrons move differently by applied field or wind. This difference is large between 70-120 kms making the conductivity large. Of course,

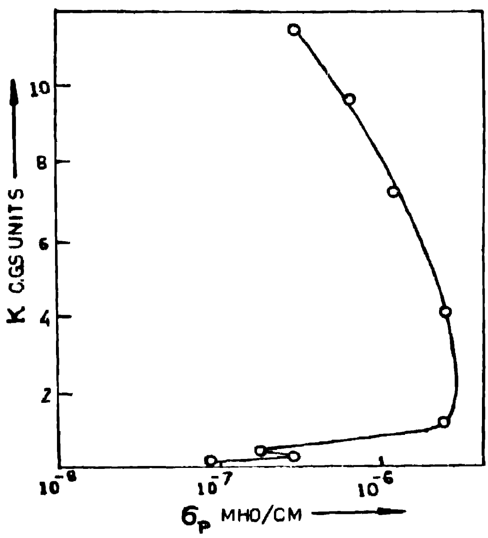

Figure Variation of K with σ_p.

below 100 kms N is small and hence σ. Above about 125 kms, the dynamo action contributes mainly to σ. The drift arises due to the coupling between E and F regions, magnetic field as well as wind. Pedersen conductivity in this regien will depend upon the electron density (N), the collision frequency (ν) and the gyro-frequency (ω_i). ω_i may be taken in the form used by Agarwal (1972) and Ramanna and Rao (1962). However, Misra and Chakravarty (1978) and Mitra and Sarada (1962) have discussed about the collision frequencies. As ν_{ee} dees not contribute to absorption mechanism the expressions for ν_e have been given by Ginzburg (1964) and Misra and Chakravarty (1983). For collision frequency of ions, discussions have been made in Thrane and Piggot (1966), Nicolet (1959) and Ramanathan *et al* (1961). The variation of magnetic flux density (B) with altitude may be considered in the light of Datta and Datta (1959) and Misra and Chakravarty (1977).

Computation of K from eq. (1) has been done using data from Physical Research Laboratory, Ahmedabad (1987) and taking σ_p and T from the same data, the variation of K against σ_p has been shown in Figure 1. K and σ with necessary parameters are shown in the table.

Table I. Showing the values of K and σ with necessary parameters.

Altitude h in kms	Electron density N/c.c.	Electron temperature T_e in °K	Thermal conductivity K in C.G.S. units	Electrical conductivity σ in mhos/cm
80	2466	183	0.2608	0.3906×10^{-7}
90	69180	183	0.298	0.2817×10^{-6}
100	129400	194	0.3516	0.1951×10^{-6}
120	164800	331	1.2575	0.2730×10^{-5}
140	216800	539	4.0652	0.2824×10^{-5}
160	280500	685	7.2793	0.1354×10^{-5}
180	280500	773	9.7232	0.6226×10^{-6}
200	280500	830	11.4951	0.8286×10^{-6}

3. Discussions

From Figure 1, it is seen that K and σ_p does not bear a linear relation at different altitudes. It is known that below 90 kms K is much higher than σ_p due to the presence of neutral particles in large which do not contribute to σ_p. Again, above 120 kms σ_p is due to dynamo action as mentioned by Rishbeth (1981) which increases K/σ_p. At about 100 kms the coupling effect between E and F regions is strong producing large absorption of energy thereby reducing σ_p.

From Figure 2, it may be concluded that K/σ_p is not a function of T only to get a relation similar to that of Wiedemann and Franz. To generalise the fact, investigations are needed for other places also. The cause of the above result may be due to the followings :

(i) The assumption that ionospheric electrons move quite freely ;

(ii) ther factors governing the properties of the ionosphere are not steady ;

(iii) in the vertical direction the temperature gradient exists which is to some extent constant in horizontal direction ;

(iv) in ionosphere the temperature gradient is negligibly small in horizontal directions and σ_p is due to electric and magnetic fields only ;

(v) the effects of ions and neutrals as well as that due to different species are to be considered in details for further accuracy ; and

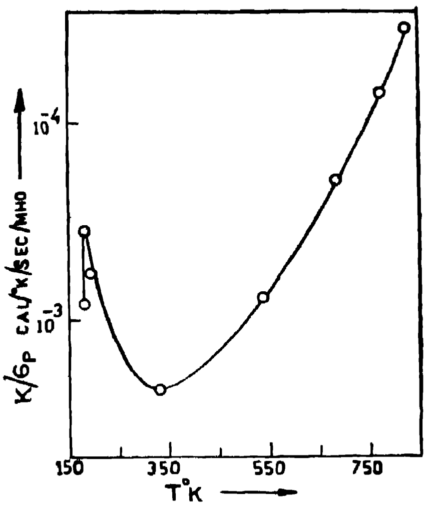

Figure 2. Variation of K/σ_p with T.

(vi) in ionosphere the polarization effects are due to electric and magnetic fields.

From the above discussions, it is clear that K and σ_p are not linearly related. It rather, depends on several other factors related to the properties of the ionosphere. Some relations in the light of Hochstim (1969) or otherwise, are needed to make the relation between the thermal and electrical conductivities clear.

Further developments about the work will be reported in due course.

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